NEW HAMPSHIRE
DEPARTMENT OF ENVIRONMENTAL SERVICES

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EVALUATION OF SEDIMENT QUALITY GUIDANCE DOCUMENT

April 2005

NHDES-WD-04-9

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EVALUATION OF SEDIMENT QUALITY

BACKGROUND

This document paper sets forth DES guidance for the application of Surface Water Quality Standards to freshwater, estuarine, and marine sediments. The narrative standards of Env-Ws 1703.19 *Biological and Aquatic Community Integrity* and Env-Ws 1703.21 *Water Quality Criteria for Toxic Substances* are applicable to sediment chemistry and biology. In addition, Env-Ws 1703.08 *Benthic Deposits* applies to sediments and refers to the physical, chemical, and biological nature of these substrates.

Sediments found in streams, rivers, lakes, and estuaries are habitat for many forms of aquatic life. This bottom-dwelling aquatic life -- including, but not limited to, amphipods, bivalves, midges, polychaetes, oligochaetes, mayflies, and cladocerans -- is intimately linked via nutrient and energy exchange webs to additional ecological resources, including finfish, shellfish, birds and other wildlife associated with surface water ecosystems. Sediments can serve as a repository and source of persistent and potentially toxic inorganic and organic chemicals. Contaminated sediments may adversely impact these ecological resources or humans who consume these resources.

APPLICABLE LAWS / REGULATIONS

Env-Ws 1703.08 **Benthic Deposits**

a. Class A waters shall contain no benthic deposits, unless naturally occurring.

b. Class B waters shall contain no benthic deposits that have a detrimental impact on the benthic community, unless naturally occurring.

Env-Ws 1703.19 **Biological and Aquatic Community Integrity**

a. The surface waters shall support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of similar natural habitats of a region.

b. Differences from naturally occurring conditions shall be limited to non-detrimental differences in community structure and function.

Env-Ws 1703.21 **Water Quality Criteria for Toxic Substances**

a. Unless naturally occurring or allowed under part Env-Ws 1707, all surface waters shall be free from toxic substances or chemical constituents in concentrations or combinations that:

(1) Injure or are inimical to plants, animals, humans or aquatic life; or

(2) Persist in the environment or accumulate in aquatic organisms to levels that result in harmful concentrations in edible portions of fish, shellfish, other aquatic life, or wildlife that might consume aquatic life.

GUIDANCE DOCUMENT

Introduction

Risk posed to sediment-dwelling organisms should be assessed according the Sediment Quality Triad approach, described in Section I below.

Certain contaminants in sediment may bioaccumulate in intermediate to higher trophic organisms. Associated risks, which increase if the contaminant has low water solubility and high lipid solubility (Log K_{ow}>4.2), should be assessed according to Section II on page 10. The document EPA-823-R-00-001 lists the "Important Bioaccumulative Compounds" (USEPA, 2000c). The EPA also addresses these persistent, bioaccumulative, and toxic pollutants (PBTs) according to their multimedia strategy, which aims to protect human and ecosystem health from these highly toxic, long-lasting substances. According to http://www.epa.gov/opptintr/pbt/cheminfo.htm, PBTs include, **but are not limited to**:

- aldrin/dieldrin
- benzo(a)pyrene
- chlordane
- DDT, DDD, DDE
- hexachlorobenzene
- alkyl-lead
- mercury and its compounds
- mirex
- octachlorostyrene
- PCBs
- dioxins and furans
- toxaphene

I. Sediment Quality Triad Approach for Sediment-Dwelling Organisms (addresses Env-Ws 1703.08 and 1703.19)

Adverse effects on sediment aquatic life will be assessed using the Sediment Quality Triad approach (USEPA, 1992). This methodology integrates both chemical and biological data in order to assess ecological resource risk. The methodology has three components that are applied sequentially and yield complementary data. The components are:

A. Sediment chemical analyses
B. Sediment toxicity bioassays (laboratory)
C. Community assessment (field)

The Sediment Quality Triad (chemistry, toxicity, and community) will be performed as this guidance document specifies in the description of each component. As outlined in the flowchart presented in Figure 1, the assessor will weigh the results of each component, as it becomes necessary to perform, to conclude whether or not the chemical contamination is impacting the benthic community. Considering the weight of evidence, the decision making process follows a matrix of outcomes (Table 1) that, if applicable, also considers the characterization of bioaccumulation risk, as determined according to Section II.

While an exceedance of the appropriate thresholds, determined in Component A of the triad, mandates further risk characterization, the severity of the risk may be so strongly predictive of impairment that the waterbody will be listed as impaired if not further characterized within an assessment period. With further characterization, the assessor may assume that Component B will reveal sediment toxicity. In this case, the assessor could skip Component B and proceed directly to Component C, i.e., community assessment. However, if the community assessment does not reveal any impact, the assumption of positive sediment toxicity must figure into the weight of evidence and typically mandates at least continued monitoring of the site for future impacts. Justification to omit Component B without this mandate may be made site-specifically. For example, any impacts would already have occurred at a site where the contamination source has been eliminated and sediment contaminants have been present for a significant (depending on site conditions) length of time. This determination will be made at the discretion of DES. Another option would be to perform Components B and C concurrently.

In the case of free product and observable ecological impacts that clearly indicate a violation of water quality standards, it may be more efficient to initially skip the triad and move directly to remediation. Following remediation, as a performance standard to ensure effectiveness, sediment sampling should be performed and the triad applied as applicable.

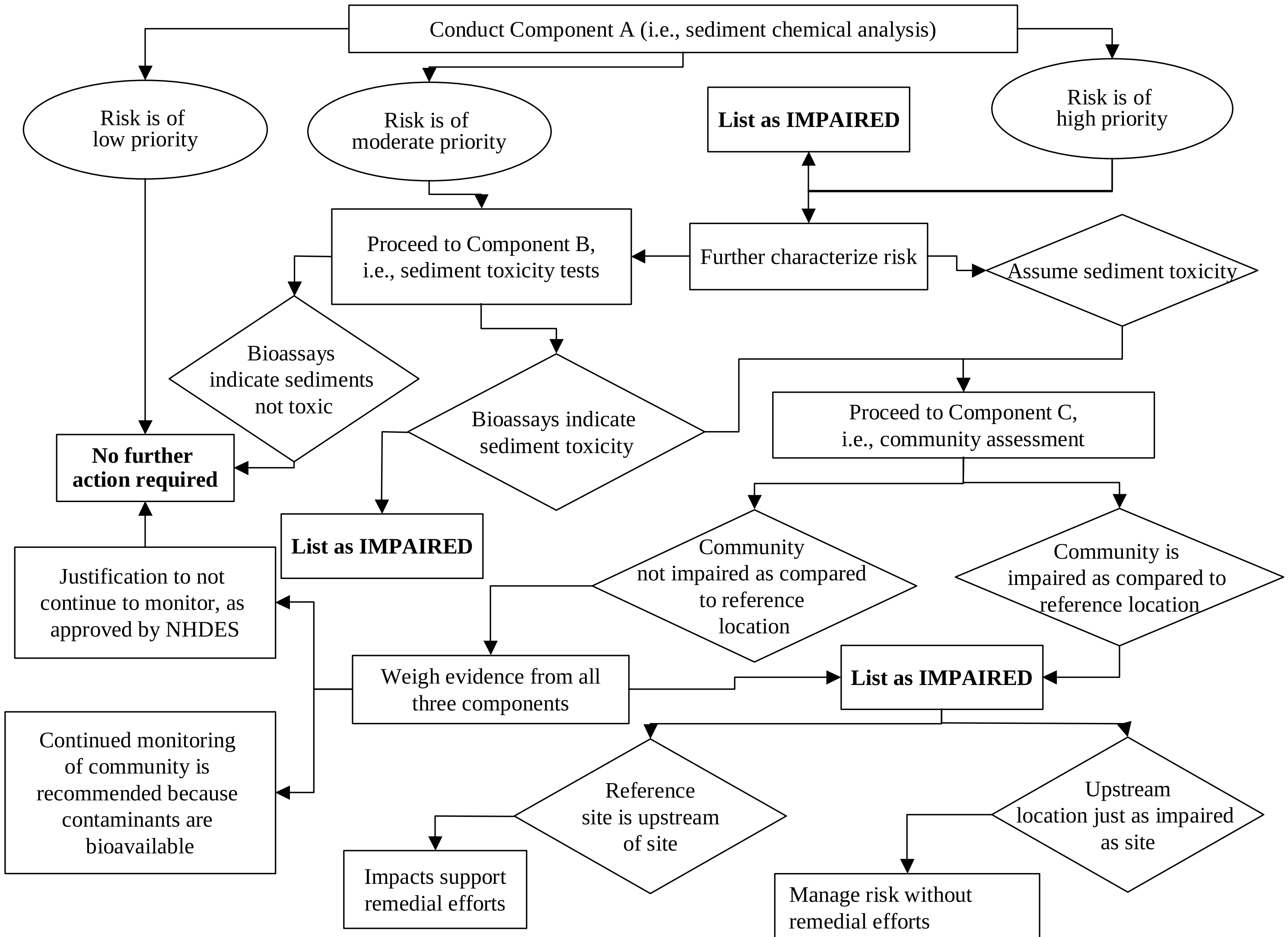

Figure 1 Flowchart of Triad Approach

Triad Components

A. Conduct sediment chemical analyses. Chemical profiles of sediment samples are compared with standard screening level reference values.

Sediment samples shall be collected in accordance with standard protocols (e.g., USEPA EPA-823-B-01-002, 2001; refer to www.epa.gov/waterscience/cs/collection.html for downloading this manual). The two main categories of sampling equipment are coring and grab devices. Data quality objectives and site specifics control the choice of sampling equipment.

Besides chemical concentrations, total organic carbon (TOC) and grain size should be quantified for each sample. The spatial distribution of contaminants at the site should be evaluated and compared to that at a reference near the site yet not impacted by the site, i.e., local conditions. If evidence suggests the concentrations of contamination of potential concern exceed those of local conditions, chemical concentrations of samples will be compared with published, peer-reviewed screening level contaminant lists, which include, but are not limited to:

1) NOAA 1999 – SQuiRT Tables (NOAA Hazmat Report 99-1).
2) Oak Ridge National Laboratory 1997 – Toxicological Benchmarks (ORNL ES/ER/TM-95/R4).
3) US Environmental Protection Agency 1996 – Ecotox Thresholds (USEPA EPA 540/F-95/038).
4) MacDonald *et al.*, 2000 – Arch. Environ. Contam. and Toxicology Vol 39: 20-31.

The following steps, as outlined in the flowchart presented in Figure 2, specify the sequence of events for screening at each sediment sampling location. The number of sample locations increases the statistical significance of the site risk characterization. Contaminants that have the potential to bioaccumulate must be further evaluated according to Section II.

Steps

1. For each contaminant, choose an appropriately conservative **THRESHOLD EFFECT CONCENTRATION (TEC)** and **PROBABLE EFFECT CONCENTRATION (PEC)** from available guidelines for each contaminant of concern. TEC values are screening thresholds **below which adverse effects are unlikely**. Data are typically from studies with sensitive species in laboratory exposures. PEC values are screening thresholds **above which adverse effects are likely.** For freshwater environments, although consensus-based (CB) TEC and PEC values (MacDonald *et al.*, 2000) are not the most conservative, they do have the most statistical justification. Assessors may choose thresholds from other sources provided they are at least as conservative as the CB thresholds. For contaminants with no available threshold, calculate a standard using the contaminant's surface water standard with appropriate partitioning coefficients.

For less sensitive ecosystems, as determined site-specifically and approved by DES in advance, comparisons to the contaminant's PEC alone may suffice.

2. Calculate the hazard quotient (HQ) for each contaminant detected in each sample by dividing the sediment contaminant concentration by the threshold value. An HQ calculated with a TEC (HQ-TEC) of one or greater indicates the possibility that the contaminant may adversely affect sediment organisms. An HQ calculated with a PEC (HQ-PEC) of one or greater indicates the likelihood that the contaminant will adversely affect sediment organisms.

3. According to Section II, contaminants with high bioaccumulative potential that have HQ>1 (HQ calculated with TEC) or for which a TEC is not available, must concurrently assess the risk to higher trophic organisms.

4. Qualify risk from each contaminant according to HQ as low (HQ-TEC<1), moderate (HQ-TEC>1), and high (HQ-PEC>1). Contaminants classified as moderate to high risk are retained as contaminants of concern (COCs).

5. If the sample location has at least one COC, determine its maximum HQ (HQ_{max}) calculated with TEC and PEC (or just with PEC if approved by NH DES) and proceed to Step 6. Otherwise, eliminate that location from concern.

6. Include the location in the priority list for further assessment according to its maximum level of risk. Qualify risk at each location as moderate ($HQ\text{-}TEC_{max}>1$) or high ($HQ\text{-}PEC_{max}>1$). Moderate to high risk may indicate a surface water quality violation.

7. Sample locations with moderate risk priority require additional risk characterization according to Component B of the triad. Sample locations with high-risk priority are assumed to be impaired and will be listed as such unless additional risk characterization according to Components B and/or C suggest otherwise.

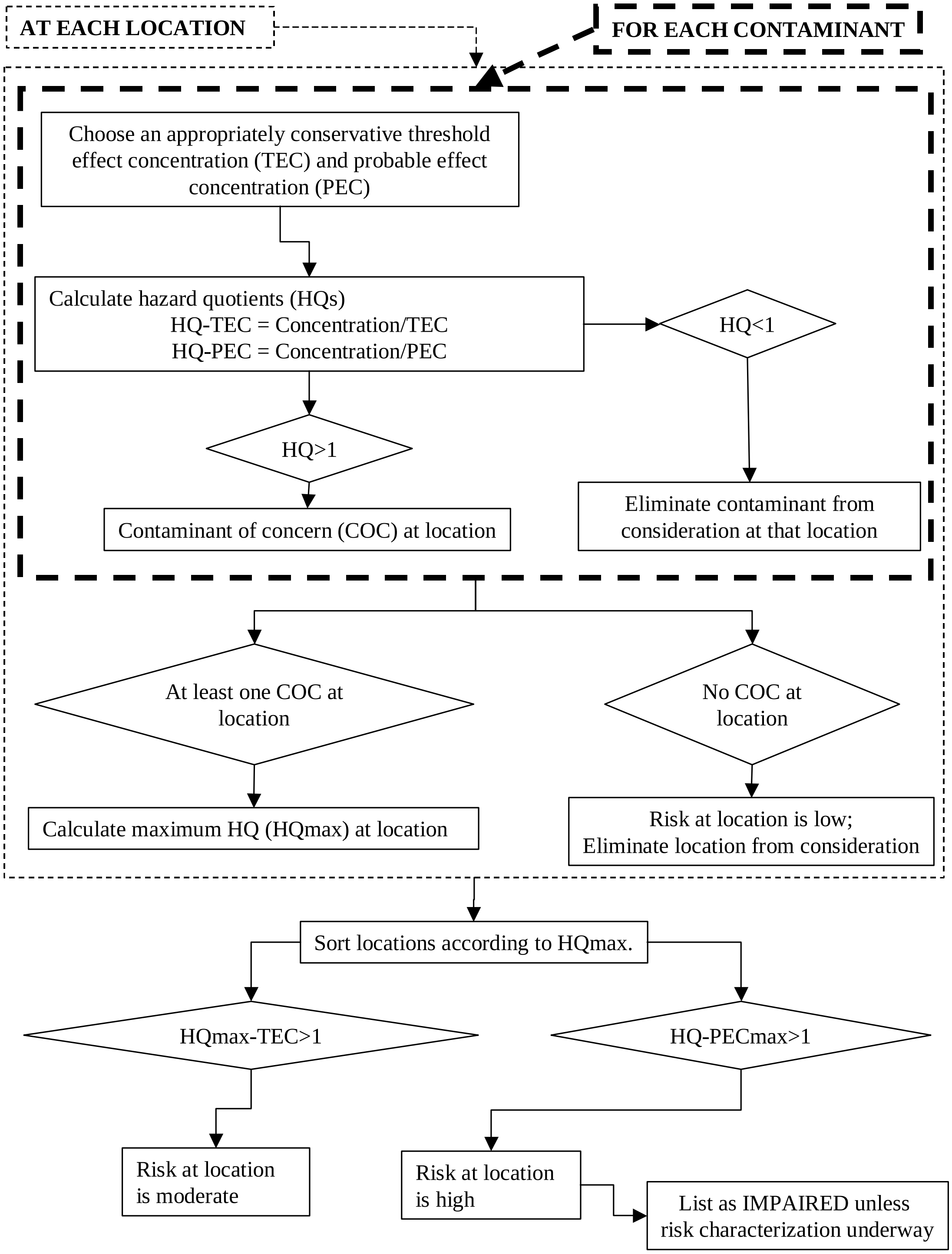

Figure 2 Flowchart of Component A of Triad Approach

B. Conduct sediment toxicity bioassays using sediment samples from potentially impacted sites

Additional sediment samples will be collected by standard protocols (e.g., USEPA EPA – 823-B-01-002, 2001) and used in standard sediment acute and chronic toxicity tests (e.g., EPA 600/R-99/064, 2000, EPA 600/R-01/020, 2001, EPA 600/R-94/025) with test organisms most appropriate for the site. Typical test organisms appropriate for freshwater environments include the amphipod *Hyalella azteca (H. azteca)* and the chironomids *Chironomus dilutis (C. dilutus)* (formerly known as *C. tentans)* and *Chironomous riparius*. Typical test organisms appropriate for marine environments include the amphipods *Rhepoxynius abronius, Eohaustorius estuaries, Ampelisca abdita, and Grandidrerella japonica*. More than one organism should be evaluated for each sample location. Sample methodology, toxicity test, and test organism(s) are subject to review and approval by DES. If sample collection is not feasible due to sediment characteristics, alternative analyses, e.g., pore water analyses/toxicity, may be substituted for sediment toxicity bioassays, but only upon prior approval by DES.

Although assessment endpoints are site-specific, an effect of 20 percent on the endpoint will indicate positive toxicity. In particular, a decrease in survival of more than 20 percent is generally unacceptable (Kuhn *et al.* 2002; Long *et al.*, 2001). However, when growth is the endpoint, literature (e.g., Kubitz *et al.*, 1996) supports a growth inhibition of an organism of 25 percent to be indicative of non-lethal effects.

Potential endpoints are a function of the duration of the bioassay. Tests may be categorized as acute (e.g., 48 to 96 hours), short-term chronic (e.g., 10 days), or long-term chronic (e.g., at least 20 days). The chronic bioassays are critical to evaluate impacts on survival and growth. Cost and time considerations associated with this requirement have typically rendered the 10-day bioassay to be performed. However, toxicity is sometimes observed only after this test would be terminated, as indicated by the long-term chronic test. Research suggests and the NH DES now recommends that, at a minimum, the long-term chronic bioassay be conducted for at least one of the organisms for samples from certain key locations. Survival and growth must be reported at the short-term and long-term marks. If significant toxicity is observed at the short-term mark, the test may be terminated then.

In the event that laboratory testing reveals acute or chronic sediment toxicity, the assessment may progress to Component C, i.e., benthic community assessment, or be deemed to pose risk. The ability and practicality of performing this third component with enough statistical power for relatively small sites, which are more typical than not at the State level, may eliminate its merit. The triad approach for which the evidence is also weighed supports the approach that if the chemistry and bioassays lead to a benthic assessment but that assessment is not rigorous enough, then the site will still be considered impacted. If chemistry indicates moderate risk, i.e., HQ-TEC>1≥HQ-PEC, and bioassays indicate toxicity, then the benthic assessment may be the deciding factor. However, if chemistry indicates high risk, i.e., HQ-PEC>1, and bioassays indicate toxicity, then the benthic assessment is not likely robust enough to outweigh the evidence of risk and may be omitted. Furthermore, sites where the aquatic chemistry is likely to change dramatically, such as for a dam removal project, may render Component C irrelevant.

On the contrary, negative toxicity for samples with high risk potential according to Component A should be considered cautiously. Prior to accepting the results, the assessor should exclude reasons for false negatives, .e.g., poor choice in test organism.

C. Conduct an assessment of community integrity

A community assessment must involve a field evaluation of the sediment community. Specifically, it is necessary to conduct a sediment biological community survey at the sampling site and compare the results with those from an appropriate, less adversely impacted reference site. The composition and structure of the benthic community will be characterized at the sample location and compared to a survey or surveys at a reference location of similar habitat but subject to less of the chemical contaminants. Standard ecological community metrics will be used to characterize the biota at both locations. The methods for benthic biological survey shall be reviewed and approved by DES in advance.

The reference location is used as a comparison to determine the level of actual risk to the site. The reference is a location that is neither impacted by the site nor by other sources. The comparison of contaminant spatial distributions for Component A may aid in locating the reference. For a river, brook, or stream, it is preferably upstream of the site. If such a location cannot be found near the site, then the reference location should be chosen from a similar watershed and metrics extrapolated to the site. If results of this comparison suggest the site is in fact impaired, a nearby location that is not impacted by the site, despite its impairments from other sources, should also be characterized as a control site so that the risk manager may make an informed decision about the relative increase in risk that is posed by the site. The risk at the site may not warrant remedial actions if nearby locations are just as impaired from other sources. Nevertheless, it is still important to understand the level of risk at hand as determined by comparison to the reference site.

II. Bioaccumulation Risk Potential (addresses Env-Ws 1703.21)

Sediment contamination can have adverse ecological effects on the benthic community and on shellfish, finfish, avian, amphibian, reptile, and/or mammal communities that are linked to benthic communities via the food web structure. Free-swimming organisms may bioconcentrate contaminants directly from the water column. However, they may also bioaccumulate contaminants via direct or indirect sediment exposure or diet.

Through the ecological processes of *bioaccumulation* (organism intake of contaminants via both water column and diet) and *biomagnification* (increased organism body burden of persistent contaminants as we move to higher tropic levels in ecosystems) contaminants in the sediments may be transferred to shellfish, finfish, avian, and terrestrial wildlife communities associated with the contaminated aquatic systems. Predator fish, birds, and other wildlife may become contaminated from being linked to bottom-feeding fish or benthic invertebrates that are laden with sediment associated pollutants via food-web transfer. This transfer can continue to human beings if contaminated fish, birds, or mammals are consumed.

The risk of bioaccumulation from sediments increases if the contaminant has low water solubility and high lipid solubility (Log K_{ow}>4.2). Heavy metals or non-polar organic chemicals, which may bioaccumulate to toxic levels in shellfish, finfish, and birds or render organisms unfit for human consumption, generally will be located in the sediments of aquatic systems. Detailed information on the chemistry and toxicity of many of the most common bioaccumulative contaminants is provided in USEPA EPA-823-R-00-001, 2000c and EPA-823-R-00-002, 2000a.

A sediment contaminant with bioaccumulation potential and, if a TEC is available, HQ-TEC>1 (determined in Component A of the triad) mandates the evaluation of actual or predicted tissue concentrations for assessment of adverse impact on relevant organisms. Relevant organisms include those species that use the contaminated site for resting, feeding, rearing, or reproduction.

A. Determine contaminant tissue concentrations for relevant organisms

Three alternative methods are available to determine contaminant tissue concentrations for relevant organisms of intermediate to higher trophic levels.

1. Use published **Biota-Sediment Accumulation Factors (BSAFs)** to estimate tissue concentrations of contaminants for relevant organisms.

   The National Sediment Quality Survey, 2nd Edition (USEPA EPA-823-R-01-01, 2000c) provides **BSAFs** for fish tissue for numerous heavy metal and non-polar organic contaminants. The Appendix to Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment (USEPA EPA-823-R-00-002, 2000a) contains additional **BSAFs** for finfish, shellfish, birds, invertebrates, plants, and other organisms.

2. Use approved models to predict tissue concentrations for relevant organisms.

   Bioaccumulation of heavy metals or non-polar organic contaminants in fish or other organisms can be predicted from sediment concentrations using equilibrium (e.g. Thomann *et al.*, 1992), fugacity (e.g., Burmaster *et al.*, 1991), or other appropriate models approved by DES.

3. Use direct measurement to determine tissue concentration of contaminants for relevant organisms.

   Direct tissue measurement is the most confident approach to determine bioaccumulation in aquatic organisms or aquatic-dependent wildlife. Direct determination can be conducted using either laboratory-exposed or field-collected organisms. For organic contaminants with a Log K_{ow} >6.5, there is a loss of linear relationship between K_{ow} and bioaccumulation. This results in uncertainty in modeled predictions of biological uptake. For contaminants with K_{ow} >6.5, direct measurement is the preferred method for assessing bioaccumulation.

B. Compare tissue contaminant concentrations with published acute and chronic toxicity values and calculate risk ratios for relevant organisms.

Acute and chronic toxicity values for ecological resources are available in numerous publications and databases. TOXNET (http://www.toxnet.nlm.nih.gov/) is sponsored by the National Library of Medicine and contains a cluster of databases on toxicology, hazardous chemicals, and related topics. The USEPA developed ECOTOX (http://www.epa.gov/med/databases/databases text.html). This database integrates AQUIRE, PHYTOTOX and TERRETOX, which are three databases that contain ecotoxicity information for aquatic life, terrestrial plants, and wildlife, respectively. Sample *et al.* (1996) provides toxicological benchmarks for wildlife. The US Army Corps of Engineers developed the Environmental Residue-Effects Database (ERED) (http://www.wes.army.mil/el/ered/index.html). It is a compilation of data from 736 studies published between 1964 and 2001 on the biological effects of many environmental contaminants found in tissues of organisms in which the effects were observed.

Risk ratios are calculated by dividing organism tissue concentrations by appropriate acute and/or chronic toxicity levels. Risk quotients of one or greater indicate the possibility of adverse effect of the contaminant on the organism. This latter outcome may indicate a Surface Water Quality violation and necessitate further action, which may be remediation, restoration, or monitoring, depending on the specifics of the site.

TABLE 1: MATRIX OF RISK CHARACTERIZATION ACCORDING TO THE SEDIMENT QUALITY TRIAD AND BIOACCUMULATION POTENTIAL				
Triad Components			**Bioaccumulation Potential**	**Outcome**
A. Chemistry	**B. Toxicity**	**C. Benthic Community**		
+	-	Not Assessed	Not Assessed	Sediment contaminants are not adversely impacting the benthic community.
+	+ (or not assessed)	-	Not Assessed	Weigh the evidence to characterize risk. If sufficient weight to Component C, the benthic community may still be at future risk for adverse impact due to sediment chemistry, requiring continued monitoring to evaluate future impacts.[1] Contaminant characteristics do not warrant bioaccumulation assessment.
+	+ (or not assessed)	-	-	Weigh the evidence to characterize risk. If sufficient weight to Component C, the benthic community may still be at future risk for adverse impact due to sediment chemistry, requiring continued monitoring to evaluate future impacts.[1] Contaminant characteristics warrant bioaccumulation assessment but impact to relevant organisms is not expected.
+	+ (or not assessed)	+ (or not assessed)	Not Assessed	Sediment contaminants at the site are adversely impacting the benthic community.[2] Contaminant characteristics do not warrant bioaccumulation assessment.
+	+ (or not assessed)	+ (or not assessed)	-	Sediment contaminants at the site are adversely impacting the benthic community.[2] Contaminant characteristics warrant bioaccumulation assessment but impact to relevant organisms is not expected.
+	+ (or not assessed)	+ (or not assessed)	+	Sediment contaminants at the site are adversely impacting the benthic community and bioaccumulation of sediment-associated contaminants has the potential to adversely impact relevant organisms.[2]
+	-	Not Assessed	+	Sediment contaminants at the site are not adversely impacting the benthic community, but bioaccumulation of sediment-associated contaminants has the potential to adversely impact relevant organisms.[2]

[1] A monitoring plan will be presented to DES for approval.
[2] This outcome indicates a surface water quality violation and necessitates further action, which may be remediation, restoration, or monitoring, depending on the specifics of the site.

GLOSSARY

BCF – Biological concentration factor; ratio of tissue residue to water column concentration at steady state.

BSAF - Biota-sediment accumulation factor; ratio of tissue residue to sediment concentration at steady state normalized to lipid and sediment organic carbon.

Biomagnification - A special case of bioaccumulation where body burdens of contaminants, normalized to an organisms lipid content, increase at successive, higher levels of an ecosystem's food web.

CB – Consensus-based; geometric mean of thresholds from a variety of sources, providing a more statistically based threshold.

COC - Contaminant of concern.

HQ- Hazard quotient; contaminant concentration divided by screening threshold concentration.

PBTs - Persistent, bioaccumulative, and toxic pollutants.

TEC - Threshold effect concentration; screening thresholds below which adverse effects are unlikely.

PEC - Probable effect concentration; screening thresholds above which adverse effects are likely.

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Approved: ____________________________________ Date: ___________

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